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Hydraulic and Other Machinery Options to Replace Traditional Swing Bridge Machinery

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Introduction

Of all of the common types of movable bridges in service today, swing bridges typically have the most antiquated machinery design. The perceived limitations of swing bridges are well known and often result in the use of bascule or vertical lift bridges where perhaps a swing bridge could be more cost effective. The purpose of this paper is to discuss the issues and limitations associated with traditional swing bridge designs and to provide alternative design concepts to traditional swing bridge machinery to address these issues. The topics to be discussed include lessons learned from a 2020 barge collision as well as commonly encountered machinery issues. The paper will discuss options for addressing some of the swing bridge machinery challenges including hydraulic options for the span drives and auxiliary systems as well as ideas to simplify and improve the reliability of traditional machinery components.

Common Issues with Swing Bridges

Given that symmetric swing bridges are counterbalanced, they generally are lighter than other bridge options and as a result can be a more cost effective option. However, there are several disadvantages that could be addressed to improve their viability. Koglin (1993) notes several concerns, including vulnerability to ship impacts, additional maintenance, longer openings, wind overhauling loads, large fender requirements, and reduced navigable channel width. While the fender requirements and the concerns with reduced navigable channel width are inherent to the swing bridge design, this paper proposes alternatives to address the other concerns noted above.

Vulnerability to Vessel Impacts

Hool and Kinne (1943) noted that swing bridges require a full opening regardless of vessel size and are more susceptible to damage from vessel collisions. Regarding the effect of vessel collisions, Hool and Kinne stated "not enough data are at hand to warrant a general conclusion, but it seems to be generally conceded that river traffic may do considerably more damage through a collision with the open end of a swing span, thus crumpling up the span and draw rest, than would be possible in the case of a bascule". The Centerville Turnpike Bridge incident illustrates these concerns. The Centerville Turnpike Bridge was struck by a barge prior to being fully open. The end of the

Photo 1: Deformation at the Rack due to a Barge Collision

span had considerable damage along with the pivot bearing and rack and pinion. While called an oil box, it is worth noting that the oil box and associated hardware is the first line of defense in the event of a vessel collision. For the Centerville Turnpike Bridge, after the pivot bearing oil box failed, the main pinion bottomed out on the rack, and the rack deformed approximately six inches.

Photo 2: Oil Box Failure after the Barge Strike

Photo 3: Location of the Initial Collision at the End Floorbeam

The National Transportation Safety Board (2021) found that the probable cause of the vessel collision was the mate misjudged the tow's speed relative to the status of the swing bridge. In their report they stated "Regulations governing bridges over navigable waters state that bridges must open promptly and fully for the passage of vessels. However, bridges can be delayed in opening for a variety of reasons, so vessel operators must be prepared to slow or stop in time to prevent an accident".

In summary, there are a few noteworthy lessons learned from this incident:

- This bridge had a single pinion, so the interior rack and the direction of the collision prevented the span from coming adrift from the pivot bearing.
- Potential collisions should be considered for the design of the oil box and/or providing other means to ensure the bridge is not able to come separate from the pivot bearing.
- The bridge had been recently rehabilitated with a new pivot bearing, but with single pinion operation, it was challenging to re-center the bridge on the pivot bearing, i.e., the bridge did not have a tendency to fully settle/center on the lower disc when turning.
- If the bridge was configured to open either clockwise or counterclockwise, the tender could have potentially opened the bridge in the opposite direction to attempt to get a more glancing collision, however in this case, the single pinion would not have been oriented to prevent the span from separating from the pivot bearing in the event that the oil box failed.
- The National Transportation Safety Board avoids assigning blame, but it is notable that they stated the vessels must be prepared to stop in time to prevent an accident, in the event of a delayed opening.
- While there was no action that the bridge tender could have taken to avoid this collision, having a means to detect ships earlier and/or increasing the operating speed of the bridge would be two ways to reduce the likelihood of a similar incident. The authors consider hydraulic cylinders or machinery utilizing modern drive capabilities to operate above base frequencies to be viable methods of operation if a quicker operation is desired.

Span Drive Machinery

The drive machinery is typically located on the movable span, as shown below. Generally, access is poor, which can result in poor maintenance practices with increased wear and tear on the machinery. The figure is taken from Hovey (1927); however, oftentimes current machinery designs look similar, with the exception being that some of the open gearing is replaced with enclosed gear reducers and shafting to an above deck operators house is avoided.

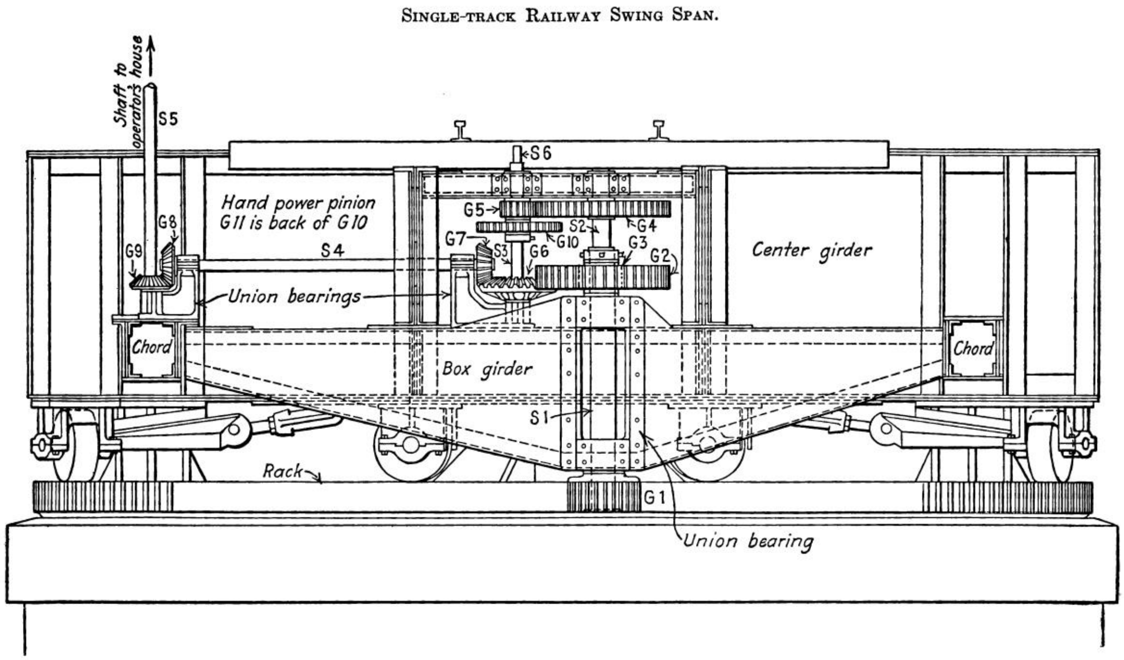

Figure 1: Illustration of Traditional Swing Bridge Drive Machinery

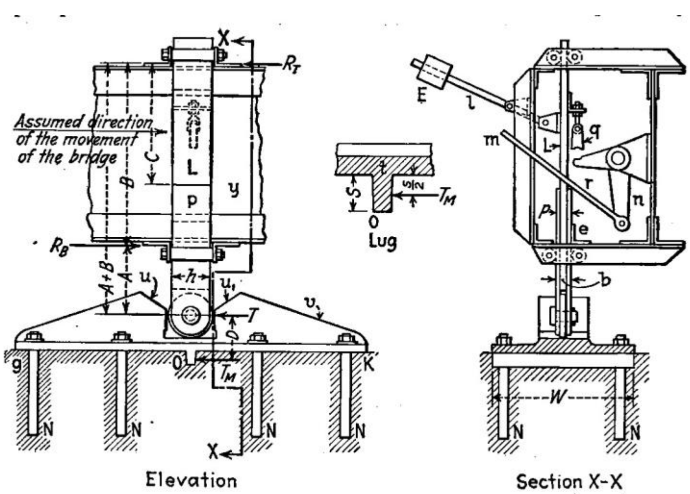

Figure 2: Illustration of Traditional Swing Bridge Latch Machinery

One of the issues with traditional span drive machinery is the amount of backlash in the gearing. This backlash, coupled with the minimal friction loads and inability to maintain a positive force on the pinion when varying speeds or in certain wind conditions, can result in impact loading on the machinery due to span inertia. Due to these issues, many bridges are operated at a reduced speed. In addition, it is frequent to have bridges with 3/8” or more of backlash and a ratio of rack radius to end of bridge of 10:1 leading to an effective backlash at the seats of 3.75” or more from the main rack and pinion neglecting all other gearing in the drive train. This issue has historically been solved with latches which operate under gravity. They must be balanced and lubricated correctly so the inertia of the latch and its imbalance cause the bridge to be locked in place only at low speeds because the machinery cannot be relied on to align the end of the bridge accurately. These complex mechanisms are often misadjusted, damaged, or inoperable after being set to latch a bridge moving too quickly. Since swing spans require a full opening to be protected by the fender system, they are at a higher risk of being struck than bascules and vertical lift bridges which provide greater clearances to reduce boat strikes even when partially open.

As an alternative to traditional machinery, opposing hydraulic cylinders provide a simple and cost effective means to operate the span, see Figure 3. Hydraulic cylinders can replace entire drive trains effectively providing a zero backlash operating system with equal or better redundancy, at a fraction of the cost. A push-pull configuration using two cylinders could be considered, but care must be taken to account for unbalanced forces as the pivot bearing would see the difference in force from the pressure being applied to the bore area of one cylinder and the annual area of the other cylinder. A push-pull configuration with four cylinders balances the forces and also provides redundancy in the event of a cylinder failure.

For the opposing cylinder arrangement shown below, different flow rates would generally be required in order to open and close the bridge at the same speed. This typically would be accomplished through pump controls. A fairly common approach is to use a pressure-compensated pump with a proportional control valve on the cylinder return line (metering out the flow). A better approach is to use an electronic displacement control on the pump. This allows you to control the flow without the need to run at an elevated pressure reducing the need for external cooling and providing greater flexibility to control the speed of the bridge. Another option used on other hydraulic bridges (e.g. East Michigan St. in Milwaukee) is a regeneration circuit, Ciampi & Kimmins (2022). In a regeneration circuit, pressure is applied to both the blind and rod sides of the cylinder when extending the cylinder. This circuit amplifies the pressure when extending the cylinder, while reducing the required flow rate, effectively making the bore end of the cylinder equal in area as the rod. By selecting the right cylinder ratio, the pressures and flow rates to extend and retract the cylinders are similar, which can simplify the hydraulic system, as well as the control system. Given that this system has none of the backlash concerns mentioned above, and the robustness of hydraulic cylinders, a bridge driven by hydraulic cylinders should be able to be operated at significantly faster speeds than with any other option.

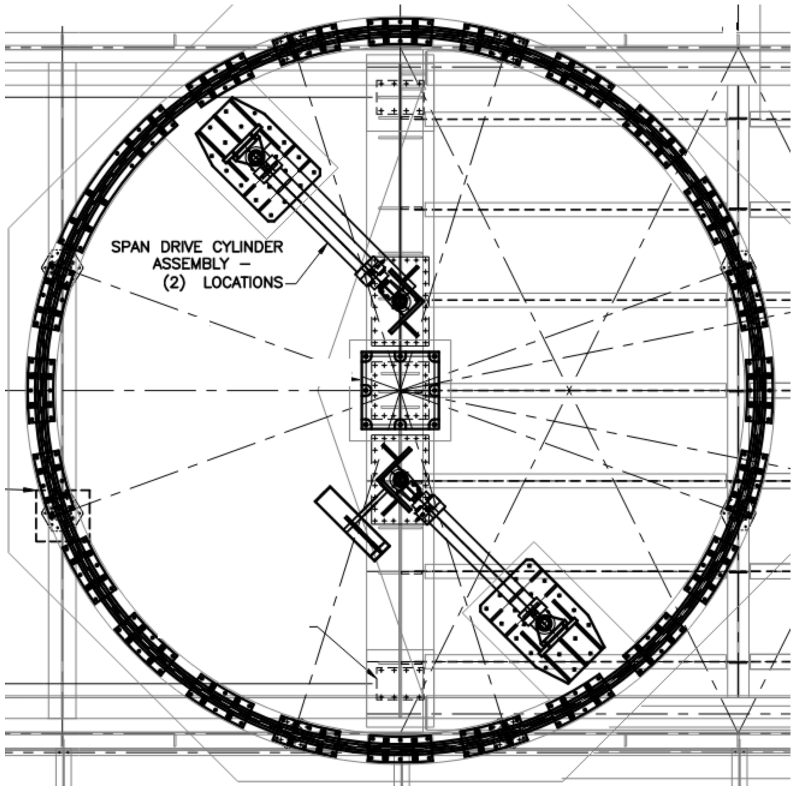

Figure 3: Opposing Hydraulic Cylinder Arrangement for Swing Bridge Operation

Swing spans can also be operated with Low Speed High Torque (LSHT) hydraulic motors. There generally is not a need for an additional gear reduction beyond the rack and pinion, so this is a fairly simple system to design and maintain. By piping the hydraulic motors together, without a flow divider, the pinion forces are inherently shared as they would be with a differential on a geared system. Emergency modes of operation need to be considered; generally, a freewheel valve should be provided to allow a pinion to be taken out of service. Note that a fixed flow is sent to the hydraulic motors, and if a hydraulic motor is taken out of service, the bridge will speed up accordingly. The authors have seen this overlooked, with the increase in power being attributed to an issue with the hydraulic system, when in reality, the power draw was increased because the bridge was being operated at an elevated speed. The potential different flow requirements for emergency modes of operation should be considered in the hydraulic system design. This can be simply addressed by reducing the number of pumps in operation or using electronic displacement control when operating on fewer motors. The benefit of using LSHT motors is the machinery is simplified with respect to a mechanical system, but there still are some of the drawbacks associated with the backlash at the rack and pinion mentioned above.

For owners that prefer a mechanical system, where space permits, consideration should be given to locating the machinery on the pier where elevations permit as opposed to the antiquated approach of locating the machinery on the swing span. Additionally, consideration can be given to electronic load sharing with multiple pinions. This permits the use of independent smaller systems mounted to the span or pier that can function should one of the systems fail, increasing the redundancy while reducing the quantity and complexity of the machinery.

Wedges

Photo 4: Hydraulic End Lifts and Sliding Live Load Shoe

Center wedges are generally supposed to be driven to firm contact, without providing uplift. If over-driven, the wedges can bind, or the machinery can potentially fail. For mechanically driven wedges, oftentimes the wedge position is set based off of proximity or lever arm switches. If a switch is off, the wedge doesn't drive to firm contact, without uplift, as intended. Hydraulic cylinders are ideal for this application. An operating pressure relief valve can be set to make sure the wedges drive until firm contact, with no uplift. A holding relief valve can be set much higher to ensure that the wedge is firmly locked in place. For pulling the wedges, a higher operating relief valve setting can be used, to overcome static friction and pull the wedges. Wedges used in this type of arrangement should use a shallow self-locking taper to prevent backdriving in addition to holding valves to provide redundancy. End wedges would be similarly controlled with the difference being that the operating relief for driving the wedge would be set higher as these wedges are intended to provide uplift. Given the larger taper required for end wedges, generally a crank is required. As an alternative, jacking cylinders with a sliding live load shoe provide a simple alternative to traditional end wedges with a proven track record on numerous bridges. This requires twice the hydraulic cylinders however since the live load bearings have no taper, back driving issues are eliminated, simplifying the machinery. This method of jacking the span and inserting live load shoes has also been used on mechanically operated bridges and is suitable with compact self-contained actuators. Note that the authors have seen several bridges which attempt to combine the live load shoe and jack into one power screw. This is not recommended, as it is not advisable to put live loads through machinery, necessitating frequent repair or replacement.

Pivot Bearings

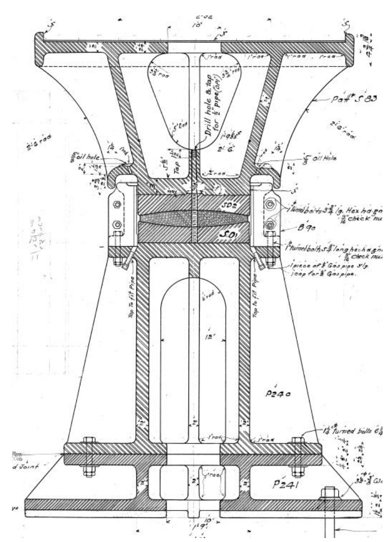

Figure 4: Three Disc Pivot Bearing

The issues with 3-disc pivot bearings are well known. Hovey (1926) stated "The middle disc of this type of center, being double-convex, is easily displaced and is very sensitive to changes of level of the center pier, and there is no tendency for it to move back into position after displacement. Bridge erectors are well aware of this fact and have nicknamed it a melon seed."

While the 2-disc pivot bearing is superior to a 3-disc bearing, there are still maintenance issues. The majority of these bearings are designed to be in an oil bath. The oil boxes are often poorly detailed with respect to gasketing and inevitably the gasket leaks. One alternative to address leaking pivot bearings is to install a gasket on the exterior of the box as shown below. After the installation of this exterior gasket, the bridge owner went from having to add oil weekly, to going months without needing to add oil.

Photo 5: Exterior Gasket to Eliminate Leakage from a Failed Flange Gasket

While oil boxes are the most common option for a pivot bearing, consideration should be given to designing a greased pivot bearing. The George P. Coleman Bridge utilizes a 60" greased pivot bearing. While this addresses some of the leakage problems associated with oil boxes, care must be taken to provide grease flow towards a purging area as new grease is added. Generally speaking, grease is recommended in plain bearings at lower surface speeds, with boundary lubrication, where retaining lubrication is challenging. When oil is used, very high viscosity, slow speed worm gearbox oils have shown the best performance.

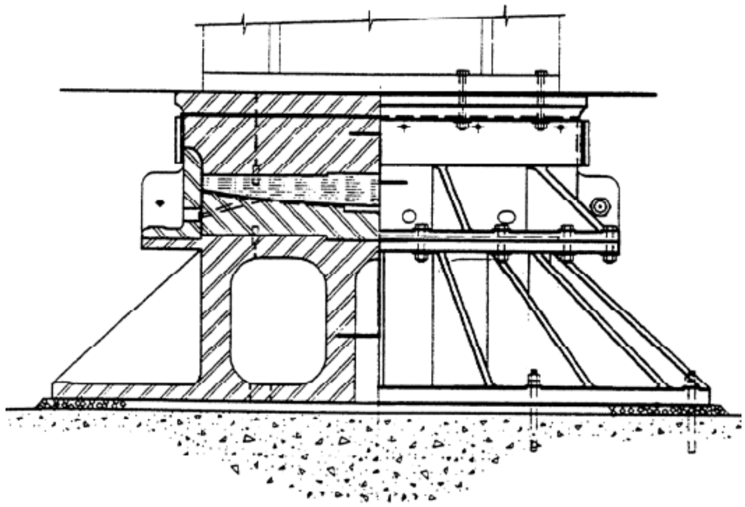

Figure 5: Two DiskBridge Pivot Bearing Illustration (Abrahams 1996)

Balance Wheels

Balance wheels are intended to help stabilize the bridge when experiencing wind loads. However, traditional balance wheels can be prone to misalignment and wear; oftentimes either riding hard against the balance wheel track, or having excessive clearance and potentially allowing the span to tip excessively and contact the wedge seats or fender. Often there are insufficient bolts and pack rust is prevalent as shown in Photo 6. Consideration should be given to design balance wheel with threaded rods for ease of adjustment as shown in Photo 7.

Photo 6: Pack Rust and Corrosion for a Typical Balance Wheel

Photo 7: Threaded Rod Balance Wheel Design for Ease of Adjustment

Centering Latches

Centering latches are used to ensure the swing bridge span is correctly aligned when in the closed position. Traditional centering latches can be prone to mechanical issues. Accordingly, the AASHTO Movable Bridge Inspection Manual considers a latch that operates properly 90% of the time or greater to be in good condition as shown below. Machinery that is so unreliable that 90% success rate for operation is considered good, is unacceptable. Some newer designs use an electric actuator to replace the latch and pawl. While this increases the reliability, it also introduces additional failure points. While the AASHTO Movable Bridge LRFD requires self-centering devices at one or both ends of the swing span, consideration should be given to replacing centering latches with a hard stop and a buffer, i.e. treat the swing bridge similar to a bascule bridge's seats. Often the buffers are placed near the end of the span, although consideration should be given to locating the buffer at the pivot pier. By locating it closer to the pivot point, the span decelerates over a larger angle for a given buffer stroke. Where systems with no backlash are provided, it is possible to eliminate a separate latch or lock bar system building the alignment mechanism into the live load shoes. Note that some misalignment capacity should always be provided where bridge alignment is critical due to differential thermal expansion, depending on the position of the sun.

Table 1: AASHTO Condition Codes for Centering Latches

Functioned Properly During the Stated Percentage of Openings	**Condition Code**
More than 90 percent	Good
Between 75 percent and 90 percent	Fair
Between 60 percent and 75 percent	Poor
Less than 60 percent	Severe

Conclusion

Swing bridges have several inherent limitations, but with innovative hydraulic options and updated machinery designs, swing bridges can be made more reliable, operate quicker, more maintainable, and ultimately be a more viable option for modern infrastructure. By addressing the common concerns and limitations associated with swing bridges, we can enhance their performance and make them a more attractive option for future projects.

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